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Application of the Area of Review Concept

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ABSTRACT

The Underground Injection Control Program Regulations require that an "area of review" be determined for new injection wells.

Analytical equations may be used to determine pressure buildup in disposal zones. However, in reviewing areas that have numerous injection wells discharging into the same zone, care must be used to take into account the effect of all the injection wells on the pressure buildup.

INTRODUCTION

The Safe Drinking Water Act charges the Environmental Protection Agency to develop minimum requirements for State programs to protect underground sources of drinking water from subsurface injection of contaminants. The Agency originally proposed Underground Injection Control (UIC) regulations specifying minimum requirements on August 31, 1976 (41 FR 36730). Significant changes were made in response to numerous public comments and the regulations were reproposed on April 20, 1979 (44 FR 23738).

One technical question that must be answered for Classes I, II, and III* injection wells is the radial extent and magnitude of pressure buildup that will occur in the injection zone around operating injection well(s). Fluids, injected under pressure into a geologic formation that has been penetrated by improperly completed or plugged wells, could move laterally through the injection zone, moving formation fluids into the improperly completed or plugged wells and upward into fresh ground water or to the surface.

There are numerous examples of this type of problem in many of the oil and gas producing States. Latta (1963), reporting about conditions in Kansas stated, "There are probably hundreds of holes drilled in the State prior to our plugging laws that were left unplugged or were improperly plugged. Where the pressure is sufficient, either natural pressure or pressure created by repressuring projects, brines may come up these holes from deeper formations and escape into fresh-water zones or to the surface."

Eddy (1956) stated, "The proper plugging of wells is probably the most important phase of Michigan's program to protect fresh water because once plugged, they stay plugged for a long, long time."

Hopkins (1963), speaking about contamination of ground water as a result of injection in an area of abandoned, improperly plugged wells, stated, "A striking example of this type of contamination was

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*In the April 20, 1979 proposed UIC Program Regulations, injection wells are classified as:

Class I – Industrial, Municipal and Nuclear disposal wells;

Class II – Enhanced recovery, hydrocarbon storage and produced fluid injection wells related to the oil and gas industry;

Class III – Frasch process, in situ gasification, solution mining, geothermal injection wells.

reported in the east-central part of the field near Bengal, Kentucky, about two miles east of Pitman. Here, a gas well used as a source for a domestic fuel supply, is 200 feet east of a pressured disposal well. The disposal well was put into operation in the latter part of October 1959. Several hours after disposal began, the gas furnace in the living room of the farm house spouted brine. The brine stopped flowing immediately after the disposal well was shut down."

"The injection of brine under pressure increased the velocity of movement of ground water in this area. In August 1960, the Kentucky Water Pollution Control Commission put dye into a disposal well operating under a pressure of 45 psi in the Louisville Limestone. The dye was dumped into the surge tank at 9:35 a.m. and at 1:02 p.m. was detected at the Gaddie Spring No. 61, plate 10, approximately 3,500 feet southwest of the disposal well."

In 1975, mud and water was forced from an abandoned well through a cement slab into a house in Shackelford County, Texas. The flow decreased when injection was stopped (Texas Railroad Commission files).

Louis R. Reeder and Associates (1977) put the problem of unplugged or improperly plugged wells in proper perspective: "Unplugged or improperly plugged wells that penetrate the host zone provide a means of escape for injected waste to mineral zones, ground-water aquifers or to the surface. The contamination of any zone outside the host rock completely defeats the concept and philosophy of underground waste injection."

"In established oil-producing areas the consideration of unplugged or improperly plugged wells is probably the most important parameter once the presence of an adequate injection horizon has been determined. This is because a large percentage of wells when plugged have been filled only with mud and have had no cement bridge plugs spotted at any interval within the well bore. Mud-laden fluid will, in time, tend to settle out thereby reducing its effectiveness as a plugging agent. Any pressure increases because of injection in any zone exposed to this mud-filled well bore will cause a fluid movement toward this area of less resistance once the pressure of the mud column is equalized. With a sufficient increase in pressure, a steady flow up the abandoned well bore will invade any horizon with a lower pressure differential."

Thus, the pressure buildup and data on completion/plugging of wells that penetrate the injection zone must be known in order to evaluate the environmental impact of an injection operation and to design an appropriate monitoring program.

AREA OF REVIEW

The reproposed UIC regulations require the permitting authority to determine, within an "area of review," whether a proposed injection operation has a potential for contaminating underlying or overlying aquifers through wells, faults or other conduits that penetrate the injection zone. This "area of review" is delineated by determining the zone of endangering influence which is ". . . that area the radius of which is the lateral distance from an injection well or injection well pattern in which the pressure change resulting from the injection operation may cause the migration of the injection and/or formation fluid into an underground source of drinking water." Thus, the "area of review" would be the area around an injection well where, during injection, the hydrostatic head of the formation fluid in the injection zone is equal to or greater than the hydrostatic head of underground sources of drinking water. The "area of review" may be defined by determining the zone of endangering influence using a Theis equation, or one of equal soundness, or by arbitrarily setting a fixed radius of not less than one-quarter mile.

When the "area of review" has been determined, each permit applicant must review the available completion/plugging records for all wells that penetrate the injection zone within the area of review. A determination must be made whether conditions exist that might allow the migration of formation or injected fluids out of the injection zone. If such conditions are found, corrective action must be taken prior to using the injection well.

APPLICATION OF CONCEPT

Warner and Yow (1979) presented a number of available analytical equations that can be used to calculate pressure buildup. Because of a desire to test the approach(es) outlined in his report, a search was made of existing oil fields in Texas to find area(s) with active injection wells and sufficient data to determine the "area of review."

Data were gathered from the files of the Texas Department of Water Resources for three areas that had active salt-water disposal wells, and in most instances the salt water was being injected into a common zone. The data obtained from the application to dispose of salt water included: the injection zone, injection rate, and, in some instances, the thickness of the formation receiving the fluid. The initial reservoir pressure, porosity and regional reservoir permeability were determined from other sources and assumed to remain constant throughout the area. The formation volume factor, system

compressibility, and viscosity of reservoir fluid were assumed, and the time of injection was arbitrarily set at 10 years.

The reservoir pressure for the multiple well case was computed using the FORTRAN program from Warner, *et al.*, 1979, with the aid of an IBM 1130 computer by application of following relationship for pressure buildup resulting from constant rate injection through multiple fully penetrating wells:

$$P_r = P_i + 70.6 \left[\sum_{n=1}^{m} \frac{q_n \mu_n \beta_n}{k_n h_n} E_i \left(\frac{39.5\, \phi_n \mu_n c_n r_n^2}{k_n t_n} \right) \right]$$

where n is the well number,

m is the total number of wells,

P_r is the reservoir pressure at radius R, psi,

P_i is the initial reservoir pressure, psi,

q is the flow rate,

μ is the viscosity, CP,

β is the formation volume factor, RB/STB,

k is the permeability, millidarcys,

h is the reservoir thickness, ft,

ϕ is the porosity, fraction,

c is the compressibility, psi^{-1},

r is the radial distance from well to point of investigation, ft,

t is the time, days,

RB is the reservoir barrels, or barrels of liquid at reservoir temperatures and pressures,

STB is the stock tank barrels, or barrels of liquid at standard temperature and pressure (520° R, 14.7 psi),

E_i is the exponential integral.

The reservoir pressure for the one well case was generated using a programmable desk calculator and the program for single well, constant injection rate from Warner and Yow (1979).

The plotter associated with our 1130 computer would not contour the maps, but rather plotted the computed pressure at various locations. Contours could then be hand drawn. In discussing this work with Don Warner at the University of Missouri, he agreed to take our data and draw the maps using the Calcomp GPCP-UU contouring program and a large computer–IBM 370-168 with a Calcomp 936 plotter.

The information used in the study represents real data coupled with assumptions; thus the results represent hypothetical cases. However, the data are sufficiently representative to indicate what should happen under certain conditions, and indicate approaches that should be taken in evaluating injection operations.

Anderson County

Data from 20 injection well applications provide the basis for evaluating the effects of brine injection in this area. The wells, which are located in the Slocum, Slocum N, Slocum W, Slocum NW, and Lake Mary fields, are designed to inject salt water into the Woodbine Formation at depths ranging from 5,234 to 5,990 feet at rates ranging from 130 to 2,000 barrels per day (bpd).

The input used in determining the resulting pressure effects after 10 years of operation are shown in Table 1. Two pressure calculations were made for the injection zone at each well. First,

Table 1. Computer Input – Anderson County

Initial Reservoir Pressure – 2120.0 psi
Formation Volume Factor (RB/STB) – 1.00
System Compressibility – 0.00000750 (l/psi)
Areal Reservoir Permeability – 1017.30 (md)
Reservoir Thickness – 100.00 ft
Reservoir Porosity – 25.000 %
Viscosity of Reservoir Fluid – 1.000 cp
Time Pressure Calculated at – 3650.000 days

Well No.	*Injection Rate (STB/day)*	*Resulting Reservoir Pressure at Injection Well (psi)*	
		1 Well	*Multiple Wells*
486	600.0	2,131	2,185
490	500.0	2,129	2,179
493	1000.0	2,138	2,186
527	200.0	2,124	2,163
542	1000.0	2,138	2,169
553	150.00	2,123	2,156
556	150.00	2,123	2,178
558	2000.0	2,156	2,200
588	200.0	2,124	2,165
602	700.0	2,133	2,183
617	1000.0	2,138	2,188
642	130.0	2,122	2,173
658	280.0	2,125	2,164
672	450.0	2,128	2,174
684	450.0	2,128	2,178
688	700.0	2,133	2,162
2	1000.0	2,138	2,183
10	400.0	2,127	2,183
17	1000.0	2,138	2,189
23	300.0	2,126	2,175

the pressure at the well with no injection interference from any other well, and second, the pressure at each well as it is influenced by other injection wells. A pressure buildup ranging from 29 to 59 pounds per square inch (psi) was noted as a result of the influence of other injection into the same formation.

The computed pressure in the Woodbine after 10 years of operation, including the influence of all wells, is indicated in Figure 1. Assuming that the initial reservoir pressure of 2120 psi in the Woodbine is uniform throughout the formation, then the static water level in wells penetrating the Woodbine should lie about 700 feet below the surface of the ground. The water level in wells producing from the overlying Wilcox, the major aquifer in the area, was about 250 feet below the surface of the ground in 1970. Thus, a pressure of about 2,330 psi or an increase of about 210 psi in the Woodbine would be necessary before movement of water into the Wilcox would be possible.

Using the "area of review" approach, there would be no zone of endangering influence for this area.

Andrews County

Twenty-one salt-water disposal applications provided the data for evaluating the pressure buildup and possible effect of injection in the Magutex, McFarland, Hutex, Glasco, and Block 5 Ellenburger fields in Anderson County. In these fields, salt water is being injected into the San Andres Formation at depths that extend from 4,800 to 6,200 feet, at rates ranging from 200 to 10,000 bpd.

Table 2 indicates the pressure buildup at each well under single and multiple well injection conditions. Note that the pressure increase from single to multi-well operations ranges from 74 to 453 psi. Well 45 is relatively isolated and shows the least influence, while well 1243 has the smallest injection rate but is greatly influenced by injection elsewhere in the area, especially well 28, which has an injection rate of 10,000 bpd.

If one examined only single injection wells and did not include the effect of other injection wells on the reservoir pressure, the "area of review" would include something less than one-quarter of a mile around specific wells (Well Nos. 981, 1177, 1232, 1251, 6, 7, 8, 11, 15, 18, 23, 24, 26, 28, and 43).

The pressure buildup in the San Andres Formation after 10 years of operation with the influence of other injection wells included is shown in Figure 2. Assuming uniform initial reservoir pressure of 1947 psi, the water level in wells penetrating the San Andres would be about 850 feet below land surface. In 1970, the water level in wells producing from the overlying Santa Rosa aquifer

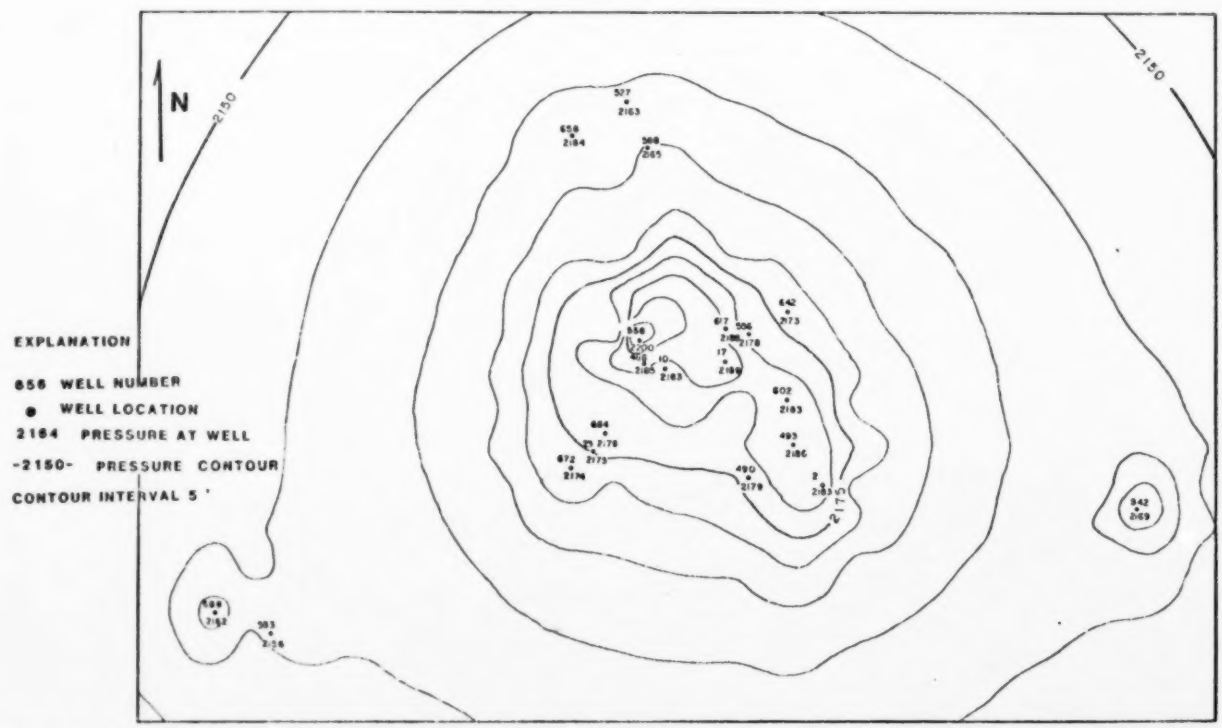

Fig. 1. Anderson County, Texas.

Table 2. Computer Input – Andrews County

Initial Reservoir Pressure – 1947.0 psi
Formation Volume Factor (RB/STB) – 1.00
System Compressibility – 0.00000750 (l/psi)
Areal Reservoir Permeability – 4.30 (md)
Reservoir Thickness – 1400.00 ft
Reservoir Porosity – 7.000 %
Viscosity of Reservoir Fluid – 1.000 cp
Time Pressure Calculated at – 3650.000 days

Well No.	*Injection Rate (STB/day)*	*Resulting Reservoir Pressure at Injection Well (psi)*	
		1 Well	*Multiple Wells*
981	3500.0	2,864	3,163
1147	200.0	1,999	2,441
1177	1400.0	2,314	2,438
1232	3000.0	2,733	3,186
1243	115.0	1,977	2,344
1251	1500.0	2,340	2,472
5	450.0	2,065	2,259
6	3500.0	2,864	3,058
7	3000.0	2,733	3,090
8	1500.0	2,340	2,743
11	2500.0	2,602	2,948
14	500.0	2,078	2,248
15	3000.0	2,733	2,928
17	400.0	2,052	2,135
18	2000.0	2,471	2,594
23	7000.0	3,780	3,959
24	2500.0	2,602	2,729
26	2500.0	2,602	2,957
28	10000.0	4,566	4,781
43	800.0	2,142	2,353
45	5000.0	3,256	3,330

was about 500 feet below land surface. Thus, a pressure increase of about 163 psi in the San Andres would be necessary before water could move from the San Andres to the Santa Rosa.

As is shown in Figure 2, the "area of review" would include the area with pressures higher than 2,110 psi, which includes all of the injection wells in the study area.

Refugio County

Seventy-four salt-water disposal applications in the Tom O'Connor and Gretna fields provided the data for evaluation in Refugio County. Salt water is being injected into the Catahoula at depths of 3,270 to 4,130 feet, at rates ranging from 300 to 17,000 bpd.

The input for determining the pressure buildup after 10 years of operation is shown in Table 3. The two pressure columns indicate the pressure buildup under single and multiple well conditions. Pressure increases, ranging from 717 to 1,239 psi, were calculated as a result of the influence of other injection wells in the area.

The pressure buildup in the Catahoula after 10 years of operation, with the influence of other injection wells included, is shown in Figure 3. With an initial reservoir pressure of 1,750 psi in the Catahoula, the water level in wells penetrating this zone should stand about 100 feet below the surface

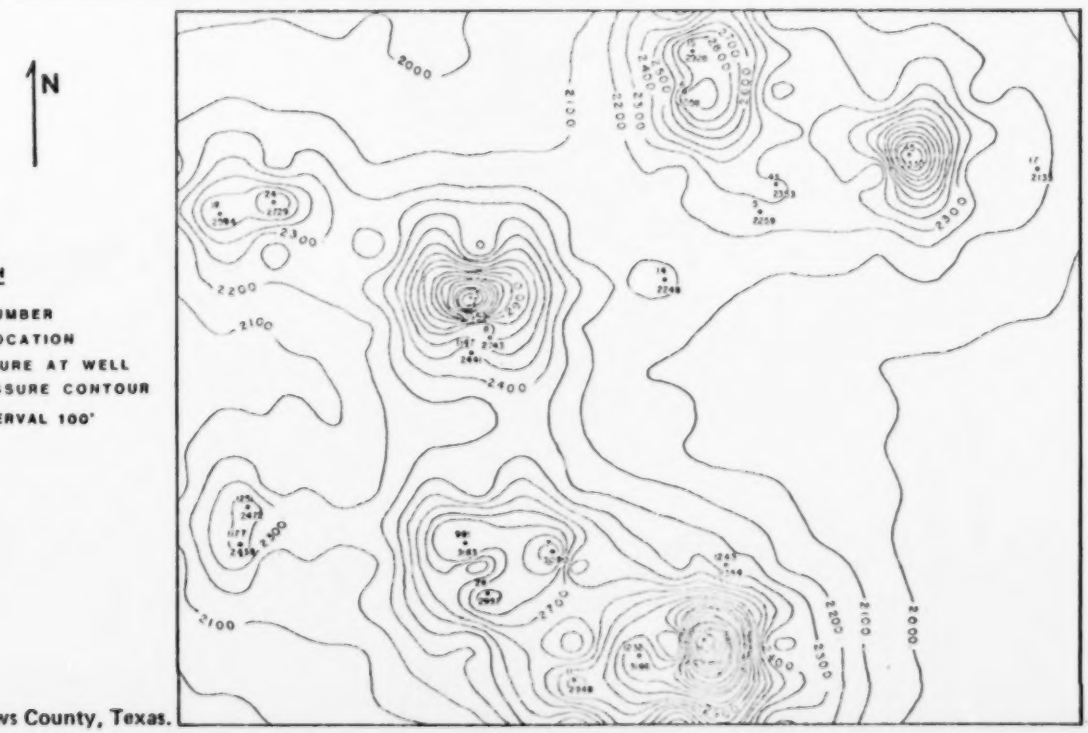

Fig. 2. Andrews County, Texas.

Table 3. Computer Input – Refugio County

Initial Reservoir Pressure – 1750.0 psi
Formation Volume Factor (RB/STB) – 1.00
System Compressibility – 0.00000750 (l/psi)
Areal Reservoir Permeability – 300.00 (md)
Reservoir Thickness – 285.00 ft
Reservoir Porosity – 30.000 %
Viscosity of Reservoir Fluid – 1.000 cp
Time Pressure Calculated at – 3650.000 days

Well No.	Injection Rate (STB/day)	Resulting Reservoir Pressure at Injection Well (psi)	
		1 Well	Multiple Wells
432	1000.0	1,771	2,798
631	400.0	1,758	2,690
647	1000.0	1,771	2,917
740	3000.0	1,812	2,900
746	4000.0	1,833	2,749
780	500.0	1,760	2,999
782	1200.0	1,775	2,950
4	300.0	1,756	2,664
5	2000.0	1,791	2,690
6	2000.0	1,791	2,753
9	2000.0	1,791	2,799
10	3500.0	1,823	2,769
11	2000.0	1,791	2,797
15	2000.0	1,791	2,962
16	2500.0	1,802	2,866
17	4000.0	1,833	2,921
20	6800.0	1,891	2,951
21	6000.0	1,874	2,867
22	5000.0	1,854	2,839
26	3500.0	1,823	2,895
27	2500.0	1,802	2,898
28	7000.0	1,895	2,987
30	6000.0	1,874	2,930
31	6500.0	1,885	2,967
32	10000.0	1,957	3,079
34	7500.0	1,906	2,790
39	4000.0	1,833	2,886
41	2500.0	1,802	2,903
42	4000.0	1,833	2,920
43	4000.0	1,833	2,797
45	10000.0	1,957	2,958
46	4000.0	1,833	2,920
58	8000.0	1,916	2,923
60	7000.0	1,895	2,923
63	3000.0	1,812	2,883
71	9000.0	1,937	2,926
73	6000.0	1,874	3,050
75	3000.0	1,812	2,994
77	3500.0	1,823	2,740
80	1500.0	1,781	2,974
83	2000.0	1,791	2,942
84	2000.0	1,791	2,699
85	3700.0	1,827	2,812
86	4000.0	1,833	2,902
87	6500.0	1,885	2,676
88	8000.0	1,916	3,029
89	8000.0	1,916	2,842
90	5500.0	1,864	2,873
91	5000.0	1,854	2,949

Table 3. Computer Input – Refugio County (Cont.)

Well No.	Injection Rate (STB/day)	Resulting Reservoir Pressure at Injection Well (psi)	
		1 Well	Multiple Wells
94	8000.0	1,916	2,874
98	5000.0	1,854	2,946
102	2500.0	1,802	2,931
108	8000.0	1,916	2,989
112	3500.0	1,823	2,648
113	7000.0	1,895	2,612
114	2000.0	1,791	2,898
118	3000.0	1,812	2,984
119	6500.0	1,885	2,763
121	5000.0	1,854	2,783
122	3500.0	1,823	2,812
123	6000.0	1,874	2,808
124	3000.0	1,812	2,938
125	4000.0	1,833	2,811
129	8000.0	1,916	2,899
131	5000.0	1,854	2,951
133	3000.0	1,812	2,829
134	4000.0	1,833	2,932
135	3000.0	1,812	2,923
138	8000.0	1,916	3,134
141	17000.0	2,103	3,244
144	5000.0	1,854	2,780
145	5000.0	1,854	2,939
146	5000.0	1,854	2,936
148	5000.0	1,854	2,918

of the ground. The water level in wells producing from fresh-water aquifers in the area stood about 50 feet below the land surface in 1972. Thus, a pressure increase of only about 25 psi would be needed to raise the water level in the Catahoula to that in the fresh-water aquifer. Therefore, under the "area of review" approach, the zone of endangering influence would be the area encompassed by pressures of 1,775 psi or greater. This includes the entire area covered by Figure 3.

Looking at single wells, with no influence from other injection wells, Well No. 141 would have a zone of endangering influence of about a 5½-mile radius. Well No. 113, at the edge of the study area, would have a zone of endangering influence of about 5¾-mile radius.

After determining the "area of review," the next step would be to review well completion and plugging records for wells that penetrate the injection zone within that area to determine the adequacy of plugging and completion techniques and whether or not the possibility exists that they would allow "the migration of the injected and/or formation fluid into an underground source of drinking water."

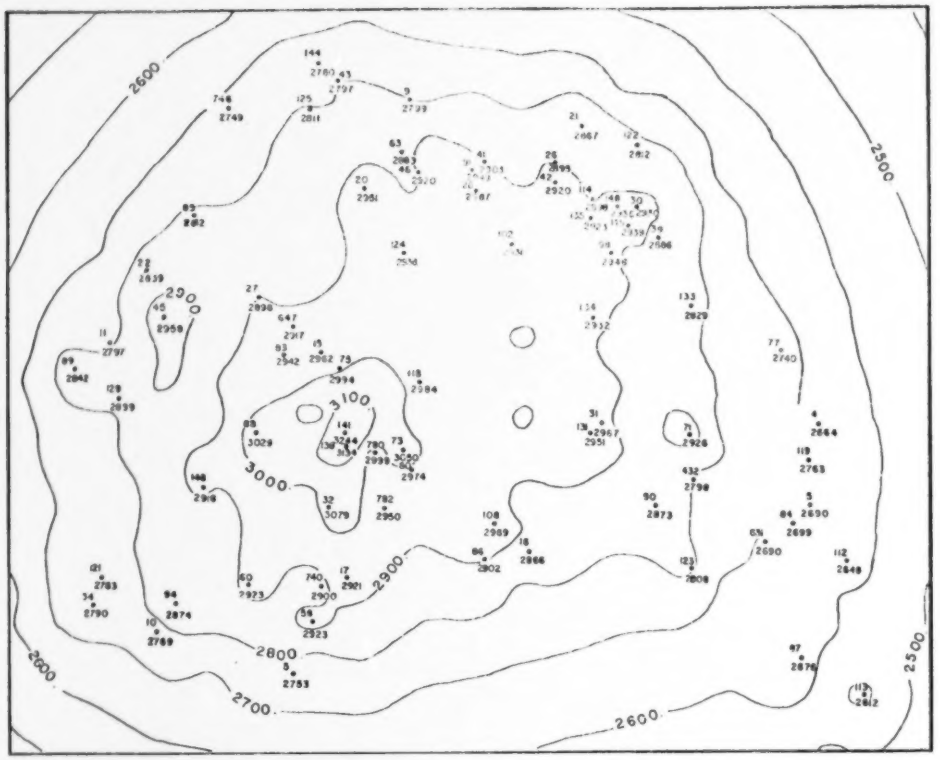

Fig. 3. Refugio County, Texas.

CONCLUSIONS

The analytical equations for pressure buildup calculations presented by Warner (1979) are quite useful and provide an excellent approach for making such determinations. A programmable desk calculator and digital computer were used in this exercise. Further discussion of the use of programmable hand calculators for such calculations may be found in Warner *et al.* (1979).

Although these are hypothetical cases, with a mixture of real and assumed data, the results point out very clearly the need to look at all injection wells in an area rather than at individual wells when attempting to determine the pressure buildup. Examination of only individual wells provides an incomplete picture of the pressure buildup in the injection zone. The data also clearly indicate that, in many situations, the "area of review" vastly differs from an arbitrarily established ¼-mile radius.

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